Experiences from the application of the new 12-point tsunami intensity scale: 2001-2014

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Quantification of natural phenomena

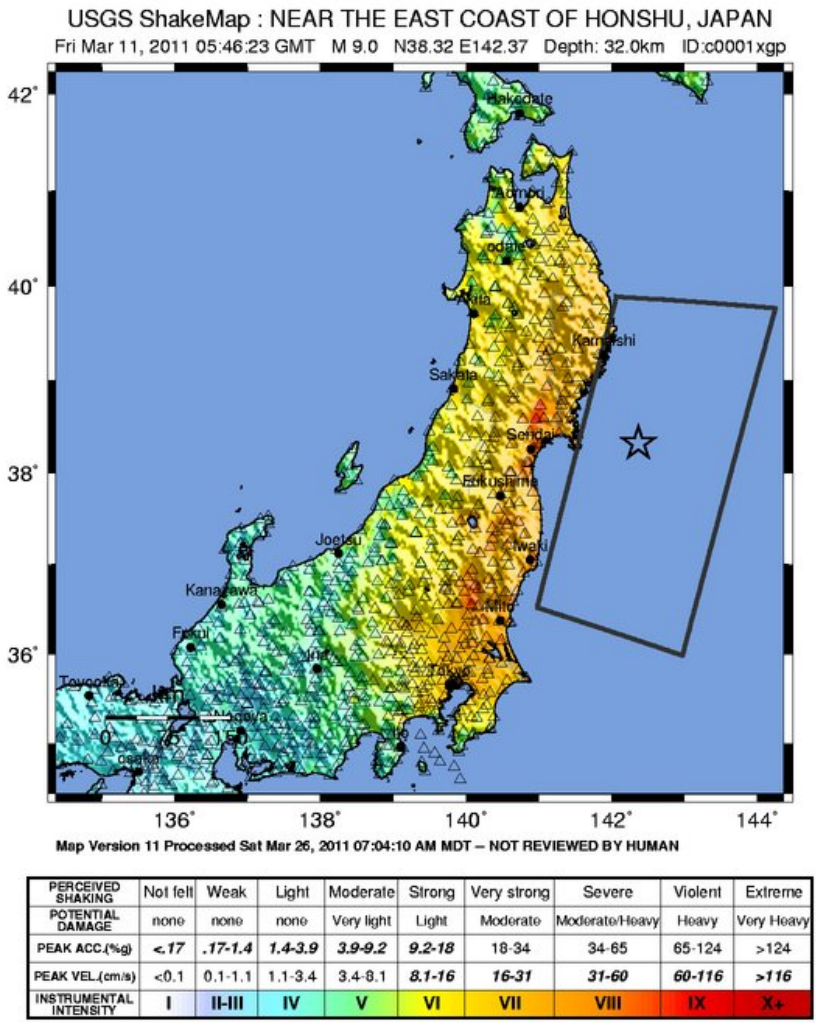
- Size

  Intensity: description & scaling of effects
  Magnitude: energy released

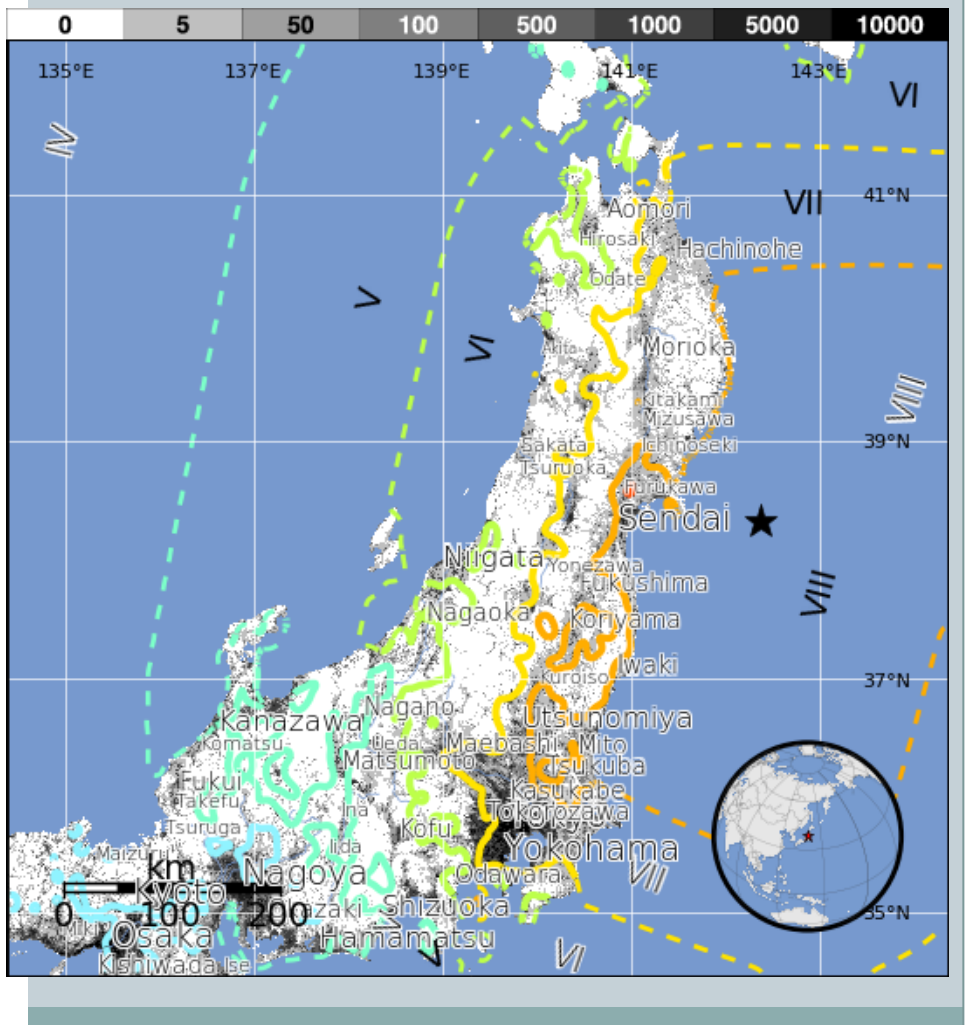
- Earthquakes: Intensity Yes! Magnitude Yes!
- Volcanic Eruptions: VEI Yes! (empirical magnitude)
- Wind: Intensity Yes! Velocity Yes! (substitute of magnitude)
- Tsunamis

  Intensity, Yes! Magnitude???

Modern use of seismic intensity



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<.17*	*.17-1.4*	*1.4-3.9*	*3.9-9.2*	*9.2-18*	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	*8.1-16*	*16-31*	*31-60*	*60-116*	*>116*
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+



Intensity advantages

- Standardized impact assessment

  use same scale / use same language

- Retrospective assessment

  historical cases

- Tsunami statistics

  recurrence, maximum size, probabilities

- Prospective assessment/Intensity mapping

  future events

- Comparative studies between regions

Standardized impact assessment use same scale/use same language

Author(s)	**Intensity Scale**	**Analogy in seismology**
Sieberg [1927]	primitive 6-point	early intensity scales
Ambraseys [1962]	improved 6-point	improved intensity scales
Shuto [2001]	developed 6-point	developed intensity scales
Papadopoulos & Imamura [2001]	new 12-point intensity	EMS 12-point intensity scales
Author(s)	**Magnitude Scales**	**Analogy in seismology**
Imamura –Iida (40's, 50's & 60's)	primitive magnitude	local Richter magnitude scale
Soloviev [1970]	primitive magnitude	local Richter magnitude
Abe [80's & 90's]	tide-gauge magnitude	surface-wave magnitude
Murty - Loomis [1980]	source magnitude	moment–magnitude

New tsunami intensity scale

Papadopoulos & Imamura (2001) scale

- 12-grade scale analogous to seismic intensity scales

- **I. *Not felt***
  Not felt even under the most favourable circumstances.
  No effect. No damage.

- **III. *Weak***
  Felt by most people on board in small vessels. Observed by few people in the coast. No effect. No damage.

- **V. *Strong***
  Felt by all on board in large vessels and observed by all in the coast. Few people are frightened and run to higher ground.
  Many small vessels move stronlgy onshore, few of them crash each other or overturn. Traces of sand layer are left behind in grounds of favourable conditions. Limited flooding of cultivated land. Limited flooding of outdoors facilities (e.g. gardens) of near-shore structures.

- **VII. *Damaging***
  Most people are frightened and try to run in higher ground.
  Many small vessels damaged. Few large vessels oscillate violently. Objects of variable size and stability overturn and drift. Sand layer and accumulations of pebbles are left behind. Few aquaculture rafts washed away.
  Many wooden structures damaged, few are demolished or washed away. Damage of grade 1 and flooding in a few masonry buildings.

New tsunami intensity scale

Papadopoulos & Imamura (2001) scale

- 12-grade scale analogous to seismic intensity scales

- **IX. *Destructive***
  Most small vessels are destructed or washed away. Many large vessels are moved violently ashore, few are destructed. Extensive errosion and littering of the beach. Local ground subsidence. Partial destruction in tsunami control forest, stop drifts. Most aquaculture rafts washed away, many partially damaged.
  Damage of grade 3 in many masonry buildings, few RC buildings suffer from damage grade 2.

- **X. *Very destructive***
  General panic. Most people are washed away.
  Most large vessels are moved violently ashore, many are destructed or collided with buildings. Small boulders from the sea bottom are moved inland. Cars overturned and drifted. Oil spill, fires start. Extensive ground subsidence.
  Damage of grade 4 in many masonry buildings, few RC buildings suffer from damage grade 3. Artificial embankments collapse, port water breaks damaged.

- **XI . *Devastating***
  Lifelines interrupted. Extensive fires. Water backwash drifts cars and other objects in the sea. Big boulders from the sea bottom are moved inland.
  Damage of grade 5 in many masonry buildings. Few RC buildings suffer from damage grade 4, many suffer from damage grade 3.

- **XII. *Completely devastating***
  Practically all masonry buildings demolished. Most RC buildings suffer from at least damage grade 3

New tsunami intensity scale

Papadopoulos & Imamura (2001) scale

- arranged according to the effects on
  - humans
  - effects on objects (e.g. vessels of variable size)
  - damage to buildings
  - nature (e.g. ground erosion)

Phucket, 2004

Photo courtesy G. Papadopoulos

Sri Lanka, 2004

Photo courtesy G. Papadopoulos

Sri Lanka, 2004

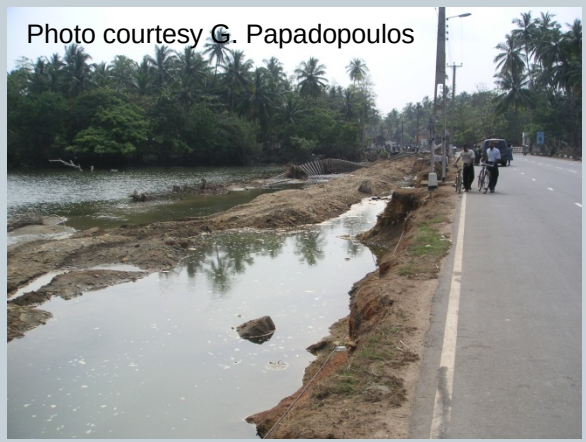


Photo courtesy G. Papadopoulos

New tsunami intensity scale

Papadopoulos & Imamura (2001) scale

- empirical relation with wave height

K	***H*** *(m)*	*i (Shuto, 1993)**
I-V	<1.0	0
VI	2.0	1
VII-VIII	4.0	2
IX-X	8.0	3
XI	16.0	4
XII	32.0	5

$*i = \log_2 H$

New tsunami intensity scale

Papadopoulos & Imamura (2001) scale

- International endorsement

- **INQUA,** seismic intensity scale, 2007.
- ***Yalciner A. et al.,*** *J. Geophys. Res., 109, C12023p., 2004.*
- ***B. Levin & M. Nosov:*** *Physics of Tsunamis and Kindred Phenomena in Ocean, Moscow, Janus-K,* p. 24-27, *2005.*
- ***Tsunami Glossary,*** *Intergovernmental Oceanographic Commission/ UNESCO & International Tsunami Information Centre, USA, p. 20, 2006.*
- ***M. Woods & M.B. Woods:*** *Tsunamis, Lerner Publ. Comp., Minneapolis,* (p. 30-32, *2007.*
- ***B. Levin & M. Nosov:*** *Physics of Tsunamis, Springer,* p.13-15, *2009.*
- ***E. Guidoboni & J.E. Ebel:*** *Earthquakes & Tsunamis in the Past: A guide to techniques in Historical Seismology, Cambridge Univ. Press, p. 510-512, 2009.*
- *etc……*

New tsunami intensity scale

Papadopoulos & Imamura (2001) scale

- Global application

- ***Indian Ocean after 2004*** (Narayan J.P. et al., *Pure & Applied Geophysics*, 163, 1279p., 2006; Rossetto T. et al., *Natural Hazards*, 2006; Maheshwari et al., *Earthquake Spectra*, 23/III, S475p.; Chang et al., *Earthquake Spectra*, 23/III, S863p.)
- ***Indonesia*** (Lavinge et al., *Nat. Hazards Earth Syst. Sci.*, 177p., 7, 2007)
- ***Japan*** (Sugawara et al., 2008)
- ***Mediterranean Sea*** (Tinti, S. et al., *Marine Geology*, 225, 311p., 2006)
- ***Portugal*** (Baptista et al., 2009), including ***Azores islands*** (Andrade C,

J. Volcanol. & Geoth. Res., 156, 172p., 2006)

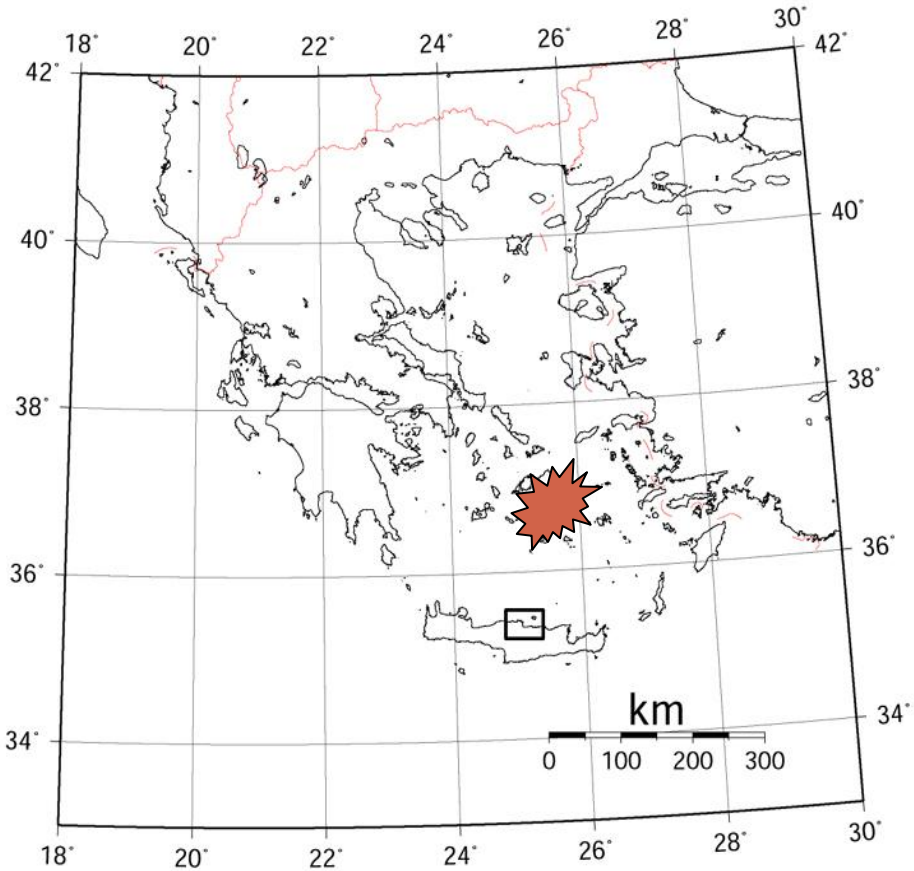
- ***Australia*** (Dominey-Howes, D., *Marine Geology*, 239, 99p., 2007)
- ***Black Sea*** (Yalciner A. et al., *J. Geophys. Res.*, 109, C12023p., 2004)

- ***Comparison with intensity scales of other phenomena*** (Friedland, C.J., PhD Thesis, Louisiana State Univ., USA, 2009).

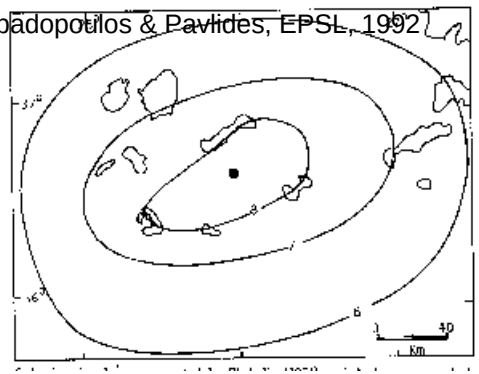
Intensity advantages

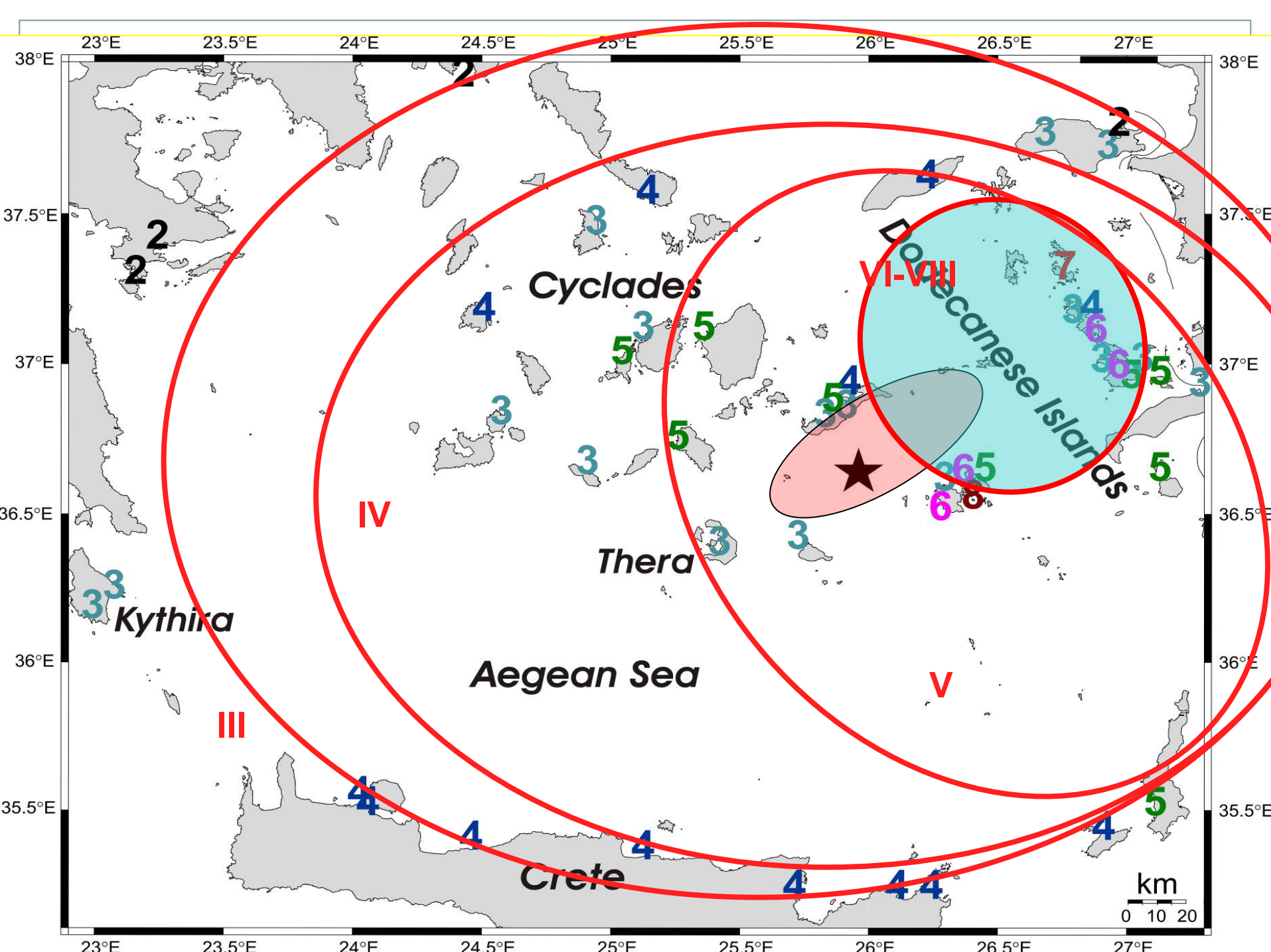
- 9 July 1956, M=7.5

Retrospective assessment of historical cases



Papadopoulos & Pavlides, EPSL, 1992

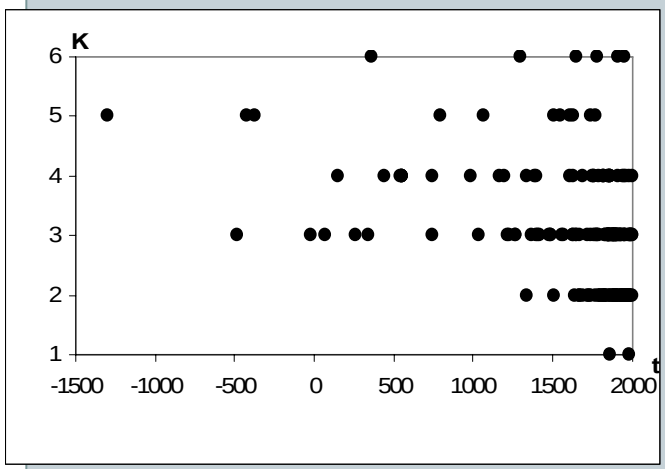


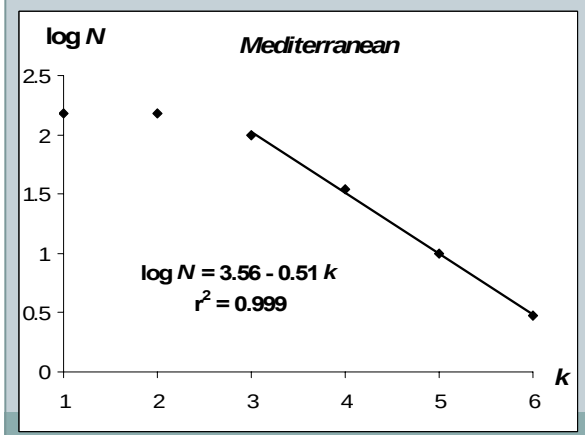

23°E
23.5°E
24°E
24.5°E
25°E
25.5°E
26°E
26.5°E
27°E
38°E
37.5°E
37°E
36.5°E
36°E
35.5°E
Cyclades
Dodecanese Islands
VI-VIII
IV
V
III
Thera
Kythira
Aegean Sea
Crete
km
0 10 20

Intensity advantages

Statistics of tsunami catalogues

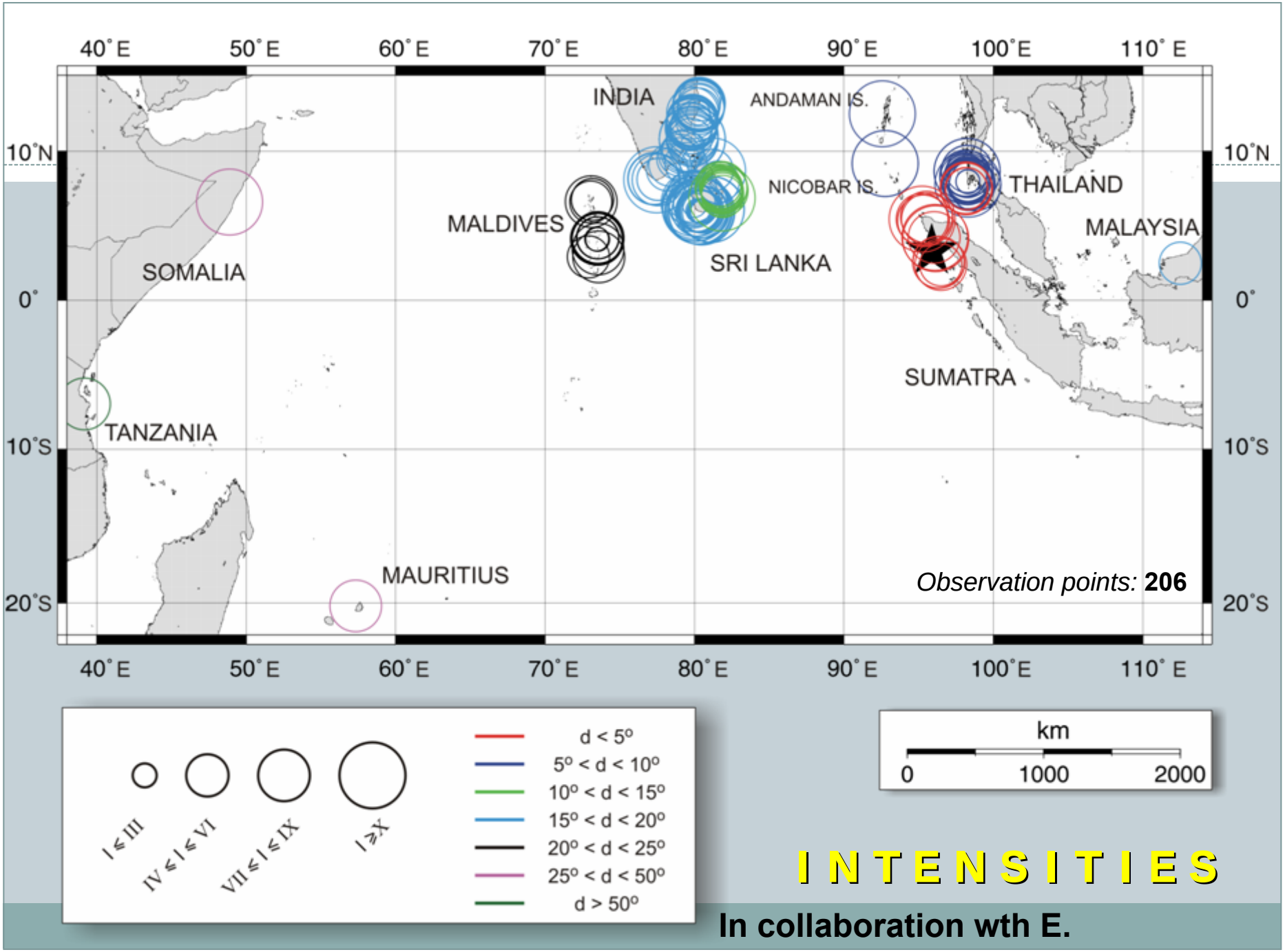
completeness analysis, recurrence, maximum size, probabilities





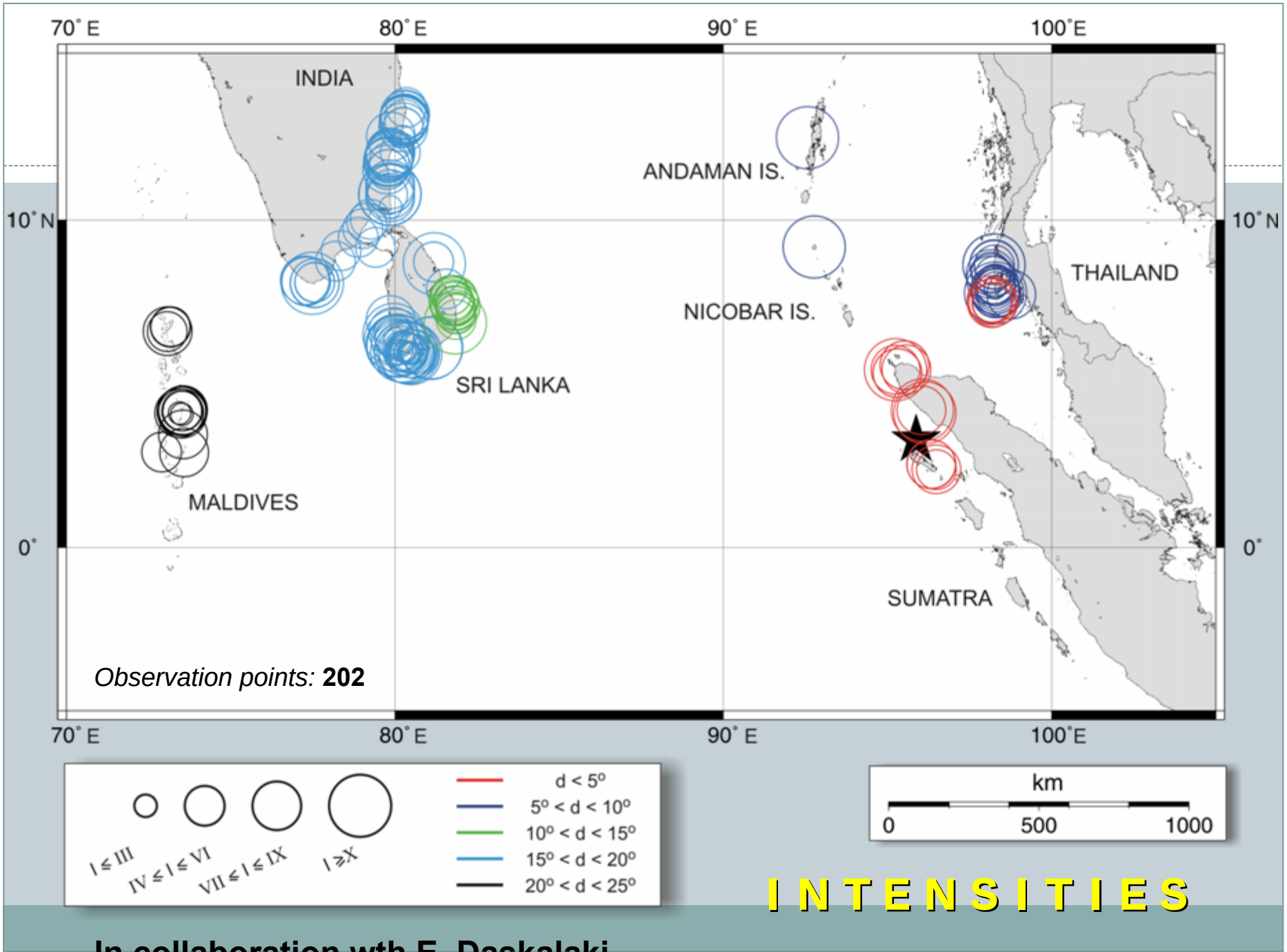
Region	*T (yrs)*				k_t		
	$k \geq$	3	4	5	6	*t(yrs)* = 1	10	100
Mediterranean Sea		4	13	41	132	2	4	6
Greece		6	24	98	399	2	4	5
Italy		26	55	115	242		2	5
Corinth Gulf		40	103	261	662		2	4

Papadopoulos & Fokaefs, ISET, 2005



INTENSITIES

In collaboration wth E. Daskalaki



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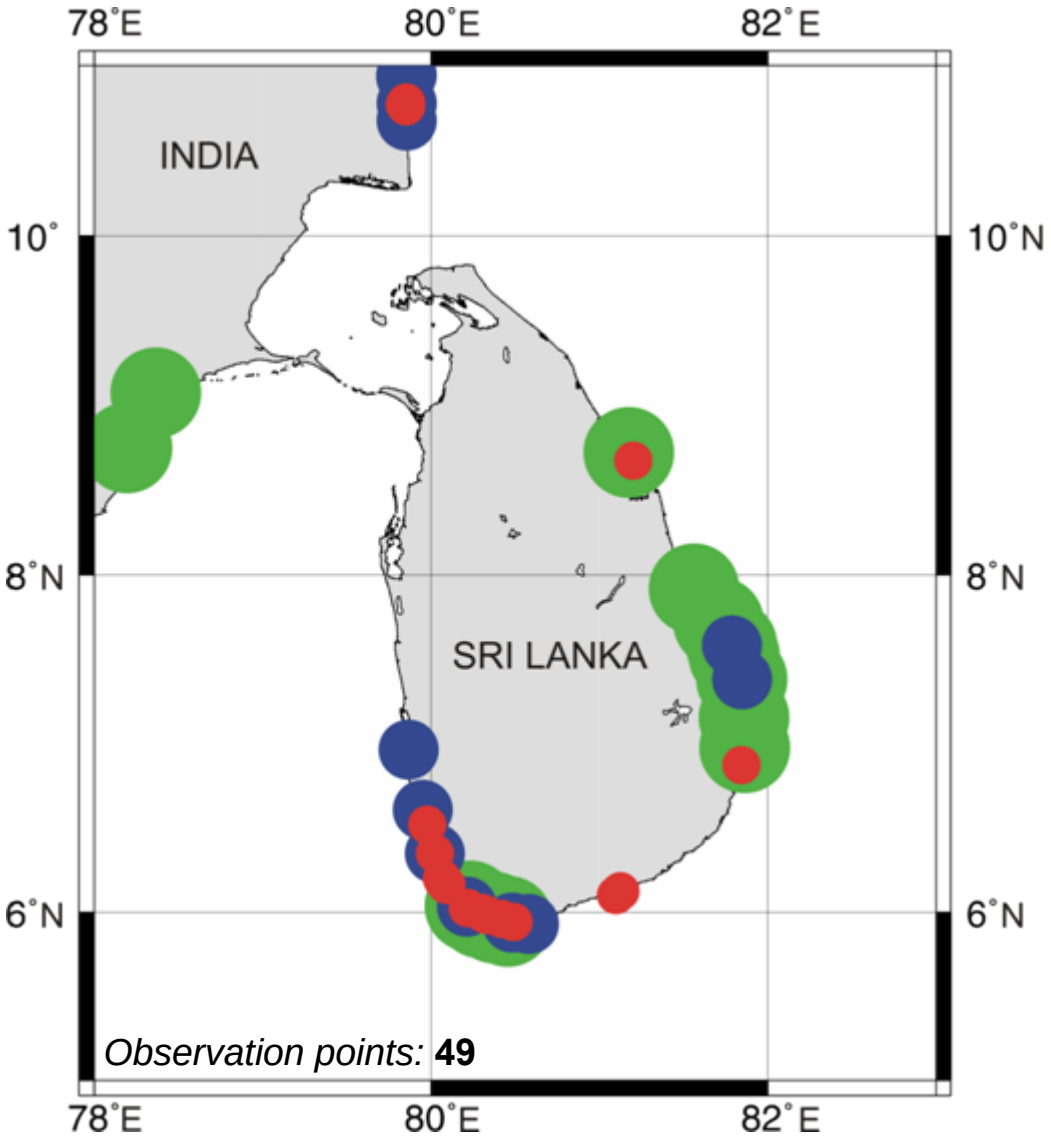
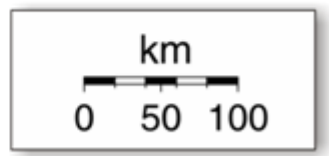
INTENSITIES





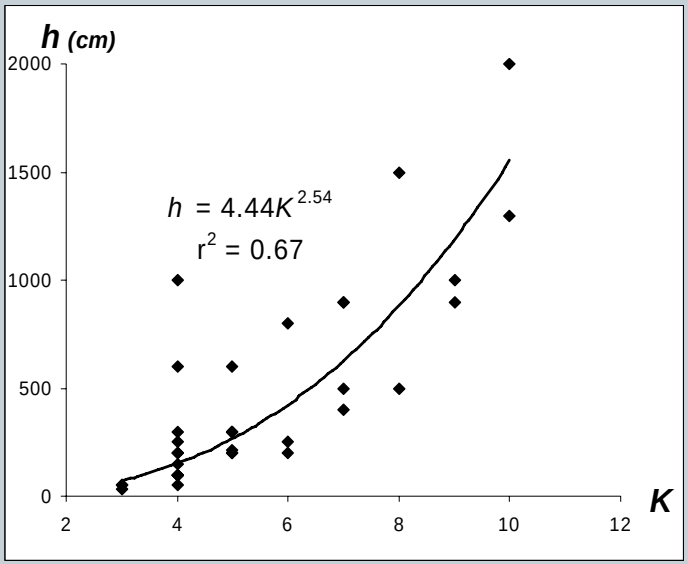
In collaboration wth E. Daskalaki

Intensity advantages

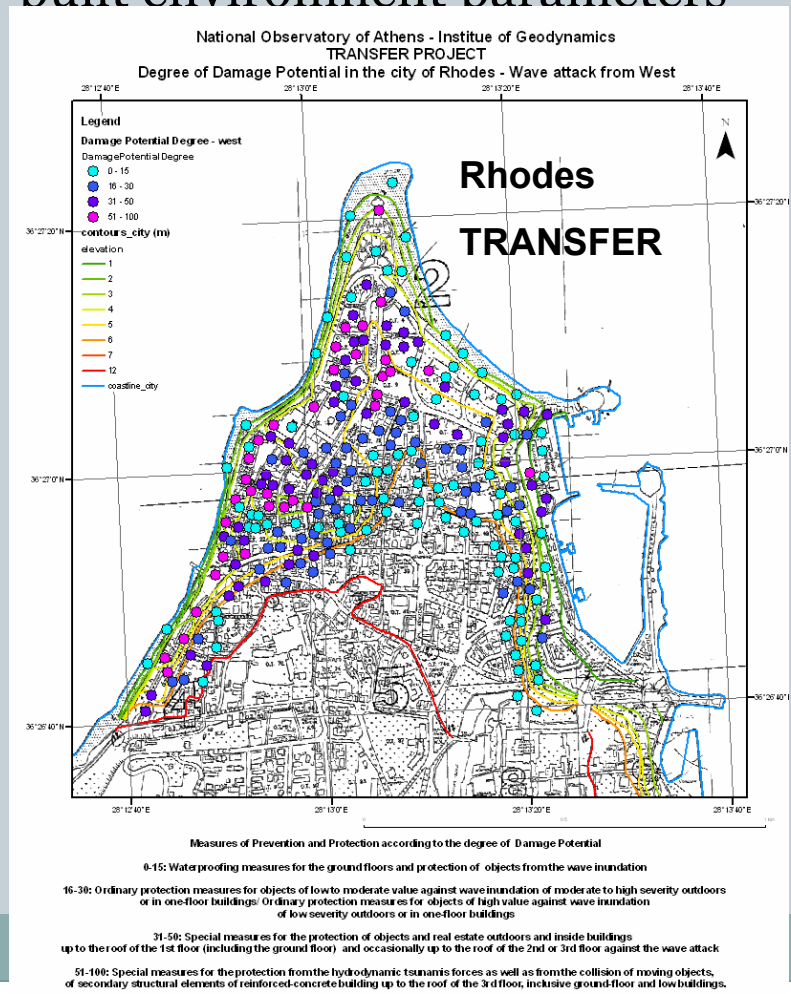
- Future studies
- Prospective assessment/Intensity mapping

  need for hydrodynamic parameters + built environment parameters

Papadopoulos & Fokaefs, ISET, 2005



- Comparative studies



Summary

- 12-point tsunami intensity scale is extremely useful parameter for tsunami

- Quantification
- Statistics/Hazard & risk assessment
- Case studies of historical events
- Damage assessment of future events
- An improved version of the 2001 scale is under preparation